

FULL LENGTH ARTICLE

# GPR investigation to allocate the archaeological remains in Mut temple, Luxor, Upper Egypt

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**Abstract** GPR investigation has been conducted on Mut temple; to the south portion of Al-Karnak temple at the eastern bank of Luxor city. Within the survey, the GPR SIR system-10A has been used connected to 100/500 MHz antenna. The present work is oriented to allocate the buried Archaeological ruins at the site, and also to evaluate the archaeological significance of the artifacts in concern to the hydro-situation. The survey is composed of three data sets; the first set (A) includes three GPR profiles located inside the temple palisade at the western bank of the holy lake, the second set (B) includes four profiles distributed on the yard between Mute and Al Karnak temples, and the third set (C) includes three profiles oriented to study the EW Sphinx Avenue front of Mute temple. The measured GPR data has been processed and visualized in different ways to show the infra-content of the artifacts in the buried subsurface of the temple. Furthermore, intensive mutual work and discussion with the local inspectorate at Luxor about the results would lead to detect the zones of possible findings and, as much as possible, to define their identities. A series of sectional GPR records, time slices, maps, and 3D graphs are introduced to represent the remains of Mut temple and its infrastructure.

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## Introduction

The temple of goddess Mut; the centre of her cult, is located south of the Karnak temple, and is surrounded with mud bricks enclosure walls. The temple is adjacent to the Avenue of Sphinxes, that extends south to north between Al Karnak and Luxor temples (Fig. 1) for a length of about 3 km and it is mostly damaged. Its position and axis is tying the back gate of Luxor temple with the front gate of Al Karnak temple via

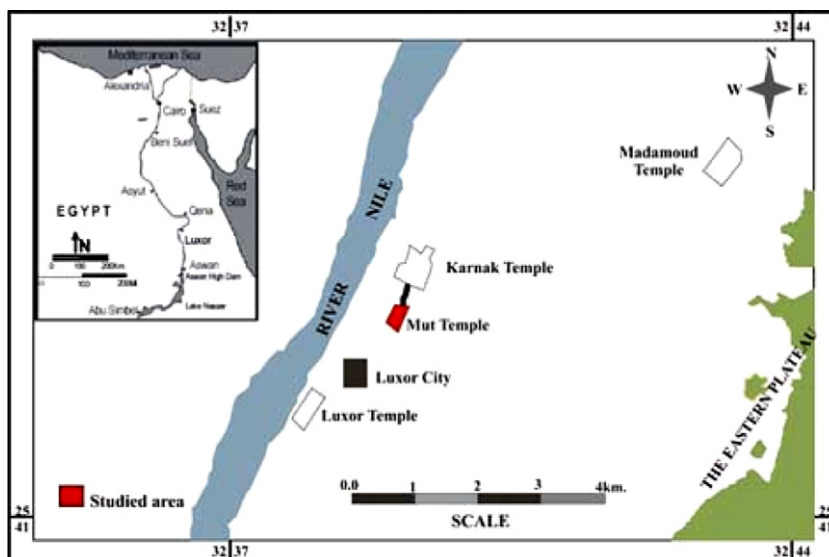


Fig. 1 Location map shows the goddess Mut temple in relation to Luxor and Al Karnak temples.

imaginary S–N line. This imaginary line is slightly tilted to the east at the north to look just parallel to the River Nile. This, in turn, could suppose an acceptable conceptual of their link as one complex together with the Nile upstream–downstream (Thames and Hudson, 2000).

The temple attains more and more attention with the time; therefore, many of scientific teams investigate the site in addition to some excavations that had been carried out inside the temple by local and international archaeological missions. The ground water level is less than 3 m and the salinity minerals of this water have a negative impact upon the different artifacts above and under the ground surface (Richard, 2007).

The geophysical contribution can solve the archaeological complications (Ismail, 2003; Sevi, 2002; El Hosary, 1994), due to this concern, and on the light of the evaluation of the archaeological background, a GPR investigation has been planned to reveal the near surface composition of artifacts, study the hydrologic situation, and to answer some questions given by the local inspectorate of Luxor city.

The measured data has been analyzed in terms of archaeological and hydrological consensus; series of 2D sections and time cuts, 3D cube and cross sections have been constructed to estimate the buried ruins, the hydro content, and to reveal the case complications.

### Archaeological and cultural impact

The ancient Luxor represents a unique phenomenon in the Egyptian cultural and archaeological history. It is a composite of two main blocks of artifacts; (1) the eastern bank with the temples of worshiping and cult is the eastern side where the sun rises; the sun then was the god Raa of Luxor or life giver, or in other word a symbol of the life, and (2) the western bank with the funerary temples and necropolises, is the side where the sun sets down, therefore, the western bank is called the city of death in some cases. The River Nile is running between the two banks from the south to the north as a line slightly tilted to the east. Further than the meaning of water towards the life consensus, the Nile part at Luxor gives the most lightening

era of the cultural history. Comparably, the existence of Luxor temple, Mut temple and Al Karnak temple on a parallel line could have the corresponding meaning (Baines and Malek, 1980).

However, in the present work, we give more concern to the goddess Mut temple (Fig. 2). It is located to the south of Al Karnak temple at about 900 ft apart from the temple of Amun-Raa on the eastern bank of the River Nile. It is centered by a crescent shaped sacred lake called Isheru, and subsidiary structures, especially the temple of Khons-pekhhrod, originally of the 18th Dynasty, and a temple of Ramesses III. Isheru is a term used to describe the sacred lake specific to precincts of goddesses who can be leonine in form. The Mut precinct's Isheru fed probably by the largest underground spring that is preserved (Velde, 2002).

During the New Kingdom, Mut, Amun and Khonsu, their son, became the pre-eminent divine family triad of Thebes. The earliest reference to Mut, Mistress of Isheru, occurs on a statue of the 17th Dynasty. Inscriptional evidence also links the site to Mut in the early 18th Dynasty reign of Amenhotep I. The earliest, securely dated Mut Temple remains are no later than the reigns of Tohotmosis III and Hatshepsut (Wilkinson, 2000).



Fig. 2 Photograph shows the general outlook of the temple Mut.

The Mut temple was built by Amenhotep III, however the propylene in the enclosure wall is contributed to the Ptolemaic (Ptolemy II Philadelphus and III Euergetes I), and later additions to the temple occurred by Taharqa and Nectanebo I among others. Hundreds of statues of the goddess Sekhmet inscribed for Amenhotep III are in museums, but some are still on site, perhaps moved from the king's mortuary temple on the West Bank.

Recent excavations indicate that much, and possibly all, of the present precinct was village settlement, until sometime in the Second Intermediate Period. Under Hatshepsut and Tutmosis III, the precinct seems to have consisted of the Mut Temple and the sacred lake and to have extended no further north than the temple's first pylon. Parts of the west and north walls of these precincts have been uncovered, including a gate bearing Tutmosis III's name and a Seti I restoration inscription. The eastern and southern boundaries of this precinct are as yet undefined (Arnold, 2003).

The Mut temple was enlarged later in the 18th Dynasty, when the Tutmosis building was completely enclosed by new construction, probably by Amenhotep III. The Mut temple's present second pylon, of mud-brick, dates no later than the 19th Dynasty, and may have replaced an earlier precinct or temple wall. Its eastern half was built of stone late in the Ptolemaic period. The temple's first pylon, also of mud-brick, has a stone gateway built no later than the 19th Dynasty, and displays at least one major repair. This pylon may also replace an earlier northern precinct wall. Also in the 19th Dynasty, Ramesses II rebuilt Temple A, which lays outside the precinct and which was already enlarged by Amenhotep III. In front of Temple A, Ramesses II erected two colossal statues, at least one usurped from Amenhotep III, and two alabaster stelae re-carved from parts of a shrine of Amenhotep II. One stele indicates that Temple A was at that time dedicated to Amun (Pinkowski, 2006).

### Previous work

From January to March, 2009, Johns Hopkins university expedition worked around the Mut lake (internal report). During that time, they rebuilt two walls on the west side of the temple and began the erection of the columns of Hatshepsut. In May 2009, work was completed under the supervisions of the SCA representative Mr. Mohamed Abd El Hameed Hamada. From April to late May, 2009 and the work includes of the following; the continued conversation about the blocks found from 2007 to 2009 during both temple and lake excavation by Lotfy Hassan and his team of conservation, the complication of reconstruction of the Hatshepsut columns by Frank Burgos and his team; and the removal of new redim from the east side of the temple that resolute from the excavation of the lake perimeter from June, 2008 to March, 2009 (Fig. 3).

In May, 2009, Lotfy Hassan and his team worked for 3 weeks carrying out several tasks. They continued to treat blocks that had been excavated during the winter of 2009 and earlier. One such block, of King Hakoirs of the 29th dynasty was found in the lake bed in the front of the quay on the west side of the lake. It has thick layers of accretion on its surface and wet layers below, now lengthy mechanical cleaning is necessary to achieve a readable surface.



Fig. 3 A photo of some excavation output.

### Data acquisition

Two main data types have been used within the present paper; the analytical evaluation of the archaeological data including the information background and excavation outputs, and an intensive GPR data set. The GPR data acquisitions are very similar to the methods used in seismic reflection. However, GPR has much higher resolution and it is sensitive to the changes in electromagnetic rather than caustic properties (Conyers and Lucius, 1996). GPR reflections are caused by electromagnetic waves encountering media that have different electrical properties namely, boundaries consisting of dielectric constant contrasts. Reflection is approximately proportional to the difference of the dielectric constants at the boundary. Antenna frequencies typically range from 10 to 1000 MHz vertical resolution varies from 1 to 1.5 m for low-frequency antennas (10–100 MHz) to 0.02 to 0.3 m for higher frequency antennas (500–1000 MHz) for most materials (Davis and Annan, 1989) (Table 1).

In the present study, GPR survey is carried out using the SIR10A system of GSSI connected to the bi static 100 and 5000 MHz antennas. The data is collected using the continuous mode of tracing, while 512 readings have been collected per trace. The global set up of the system was oriented to prospect the shallow objectives, because the unearthed archaeological stones could be buried within a depth up at 6 m or a little more according to the excavations results.

**Table 1** The values of dielectric constants range and velocities of electromagnetic waves through materials (after Daniels, 1996; Davis and Annan, 1989; Schon, 1996).

Materials	Values for dielectric constants range	Velocities of electromagnetic waves through a materials
Air	1–3	0.3 m (1 ft) per nanosecond
Limestone	4–8	0.11–0.15 m (0.36–0.49 ft) per nanosecond
Shale	5–13	0.8–0.013 m (0.26–0.43 ft) per nanosecond
Clays	5–40	0.05–0.13 m (0.16–0.43 ft) per nanosecond
Water	81	0.03 m (0.09 ft) per nanosecond

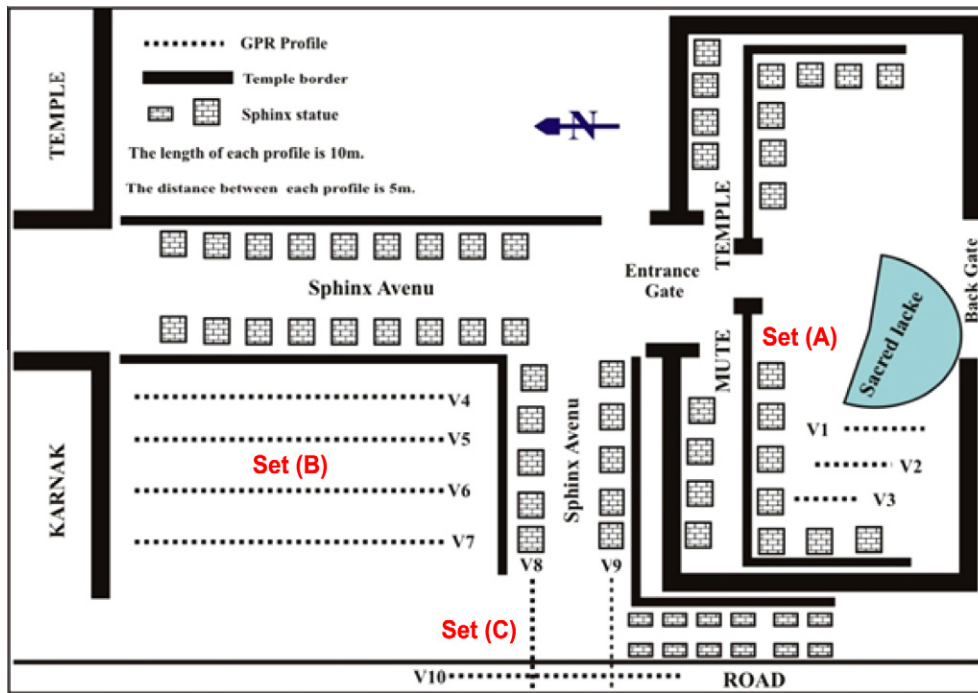


Fig. 4 Sketch map showing GPR survey net at the site of Mut temple.

Ten profiles have been conducted inside and outside the Mut temple (Fig. 4). Three sets of data have been conducted as follow; set (A) is composed of three profiles (V1, V2, and V3) conducted on the western side of the sacred lake inside the Mut temple, set (B) consists of four profiles (V4, V5, V6, and V7) on the southwestern part between Al Karnak temple and Mut temple, and set (C) consists of three profiles (V8, V9 and V10) at the extension of the Sphinxes Avenue. The site is particularly covered with some accumulations of the excavation filling outputs.

#### GPR data processing

The GPR profiles are processed by using the software program (ReflexW, 2D/3D, of Sandmeier, 2001). This program is designed for the complete processing and interpretation of 2 and 3 dimensional electromagnetic and seismic reflections. The program supports the most known GPR-data formats. A part of the standard filter algorithms utilizing wide range of special methods is available.

The measured data at Mut site has been treated over three groups; the first group processes the profiles V1, V2, and V3, the second group composes the profiles V4, V5, V6, and V7, while the third group composes the profiles V8, V9, and V10. The all data set has been basically passed through the following steps;

As a start point of the processing algorithm, the raw data has been converted into the internal format of the post processing program "REFLEXW to facilitate the data reading and on working. The three data sets have been acquired using the continuous mode. It is noticed that the raw data is displaced at about 20 ns on the TWT axis, this displacement reflects the time consumed for the direct wave composition

(Transmitter direct to Receiver, and Transmitter to Ground to Receiver). Therefore, the static correction is a basic procedure to return the ground surface to the zero time. It is a time independent correction acts on the individual traces of the GPR record. Then the data has been cross correlated and filtered using the band pass filter. As a final step of the processing, the background noise is removed and the signal of use is magnified using the energy decay function. Fig. 5 shows the stepwise processing output.

#### Interpretation of data set (A)

Set (A) is composed of three profiles located to the west of the sacred lake inside the temple of Mut (Fig. 4). The three profiles (V1, V2, and V3) are almost parallel and are located on a relative equidistance separation. The background feedback lights the near surface cultural state at Luxor as; top soil dry mud layer is laying on a wet clay layer, then a sandy mud layer and the water bearing sand layer (Fig. 6). Normally, the artifacts and the significant archaeological remains should be buried in these layers.

In general the soil layers provide very low reflections, which appear as linear reflections due to the low dielectric constant of the soil materials, but the materials of the archaeological remains have different dielectric constant, so that they give medium to high reflections. The rock types of the archaeological remains at Mut site are sandstone, granite and basalt, which normally give reflections more different than the surrounded soil layers, which make it easy to recognize the archaeological objects in the archaeological sites and allocate their depths from the obtained GPR sections (Fig. 7).

However, within the three profiles, several objects of archaeological interest could be defined. Over the vertical

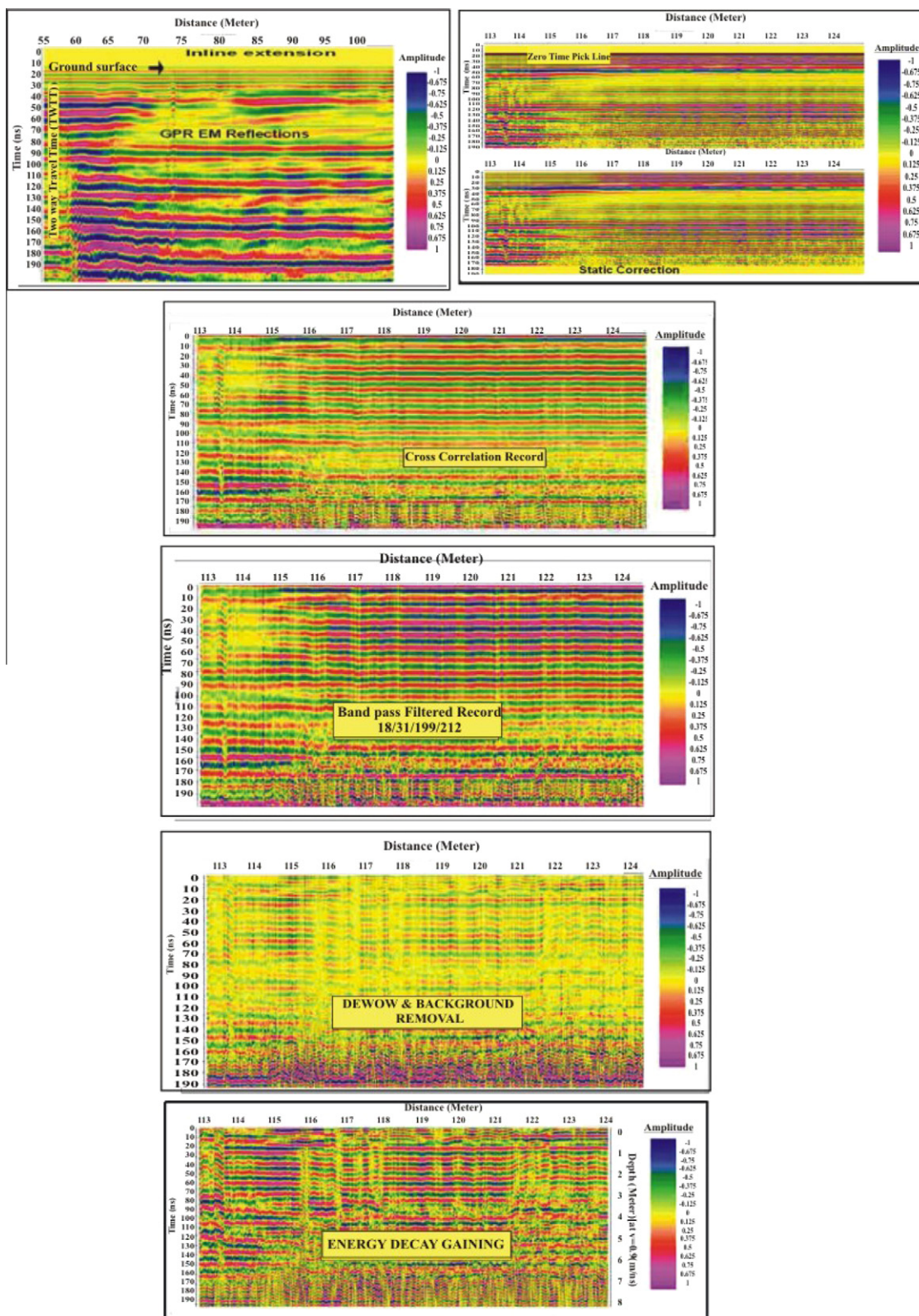


Fig. 5 The stepwise processing output.

range, the objects could be classified to shallow objects and deep object. The relation between the two object kinds is a matter of analytical discussion with the archaeologist, the reason for that is the host cultural layers are different. Some

dedications inform that the remains of this place could be contributed to priests houses, therefore a downward time slicing became of interest to follow their lateral extensions (Fig. 8).

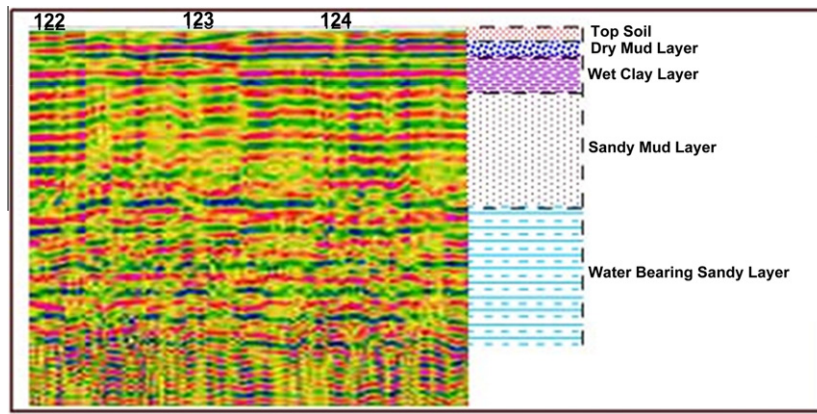


Fig. 6 An interpretive record for the cultural soil sequence at Luxor.

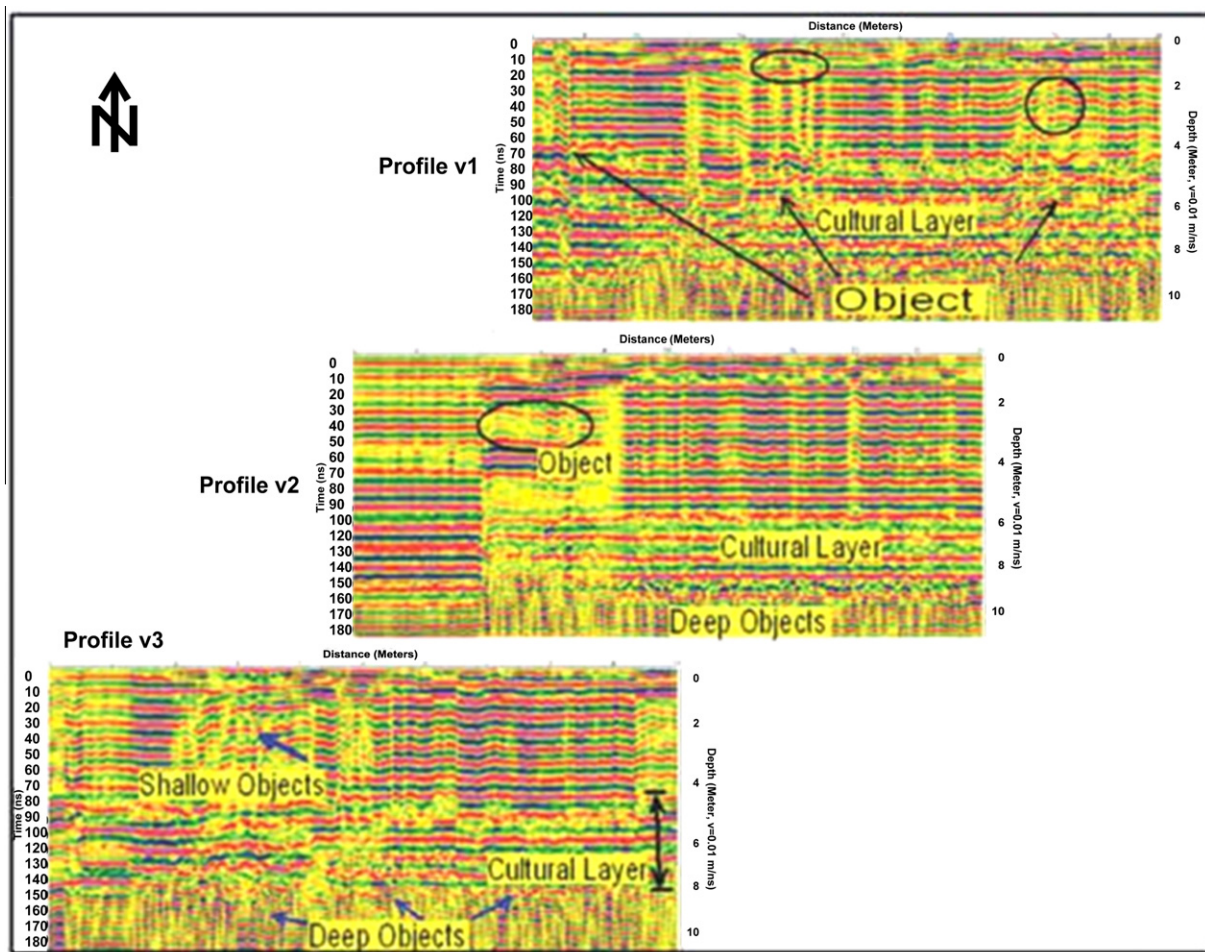


Fig. 7 The comparative profiles V1, V2, and V3 in correspondence to their location.

Furthermore, the time slices have been eliminated and analyzed manually to prospect for archaeological remains. Fig. 9 represents a moderate depth (around 4 m) as an example for such analysis, in which the shallow and deep artifacts, in addition to linear objects, could be defined.

*Interpretation of data set (B)*

This data set is composed of four profiles located outside the main gate entrance of the Mut temple between two sides of Sphinx Avenue (Fig. 4). The profiles have a proper distribution

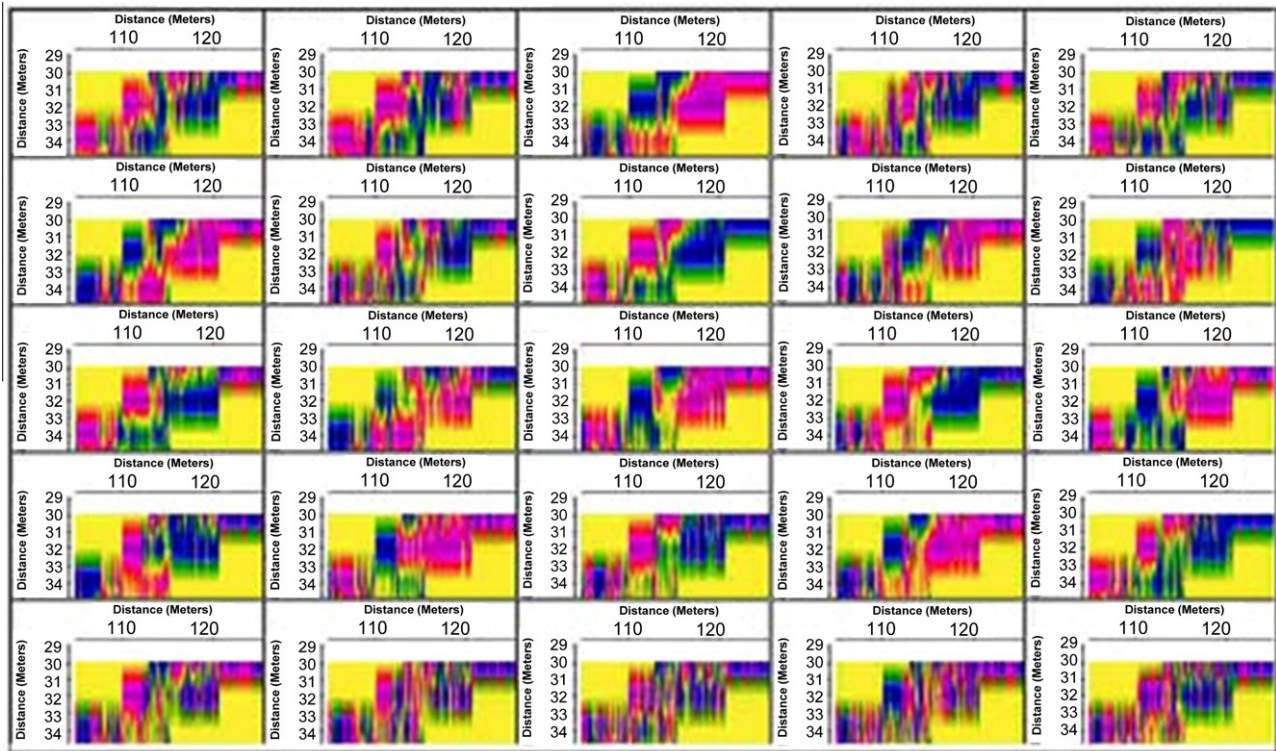


Fig. 8 The downward time slicing at Mut area, the clear yellow zones are out of survey area.

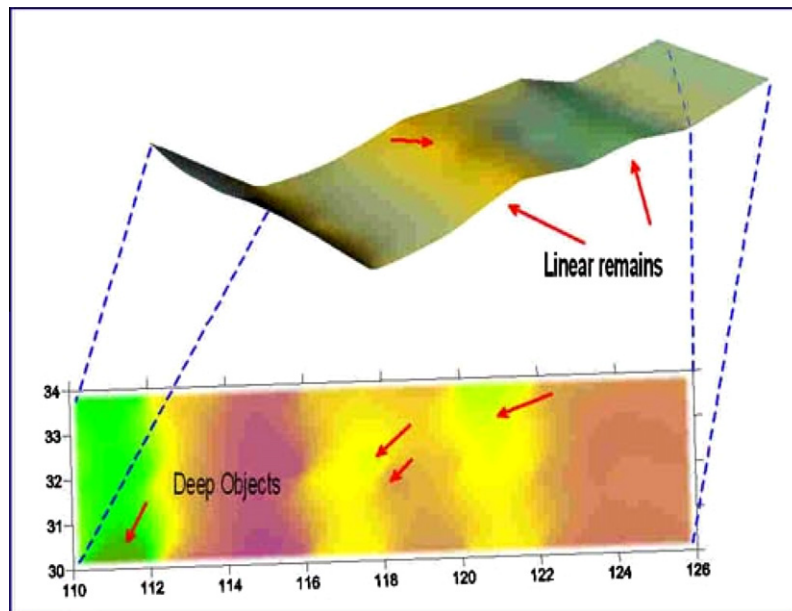


Fig. 9 A time slice represented in a form proper for individual analysis over the depth range.

for a proper 3D analysis (Fig. 10). An object could be easily defined on the GPR, it is marked with an arrow on the profiles V5, V6, and V7.

The previously mentioned object on the profiles (Fig. 10) has been visualized on a Cross Cut Section presentation composed of profile V5 and the time slice at 120 ns intersecting in the 3D plane with a virtual section cutting V4, V5, V6, and V7

at their mid points. The object is referenced with an arrow (Fig. 11).

The GPR reflection on the 2D section shows only the object, to observe its lateral extension, time slices over 1.5 period ( $\approx 12$  ns). Fourteen time slices have been presented as a series in Fig. 12. The arrows refer to the same object but still unclear, therefore, the same data have been presented as surface and

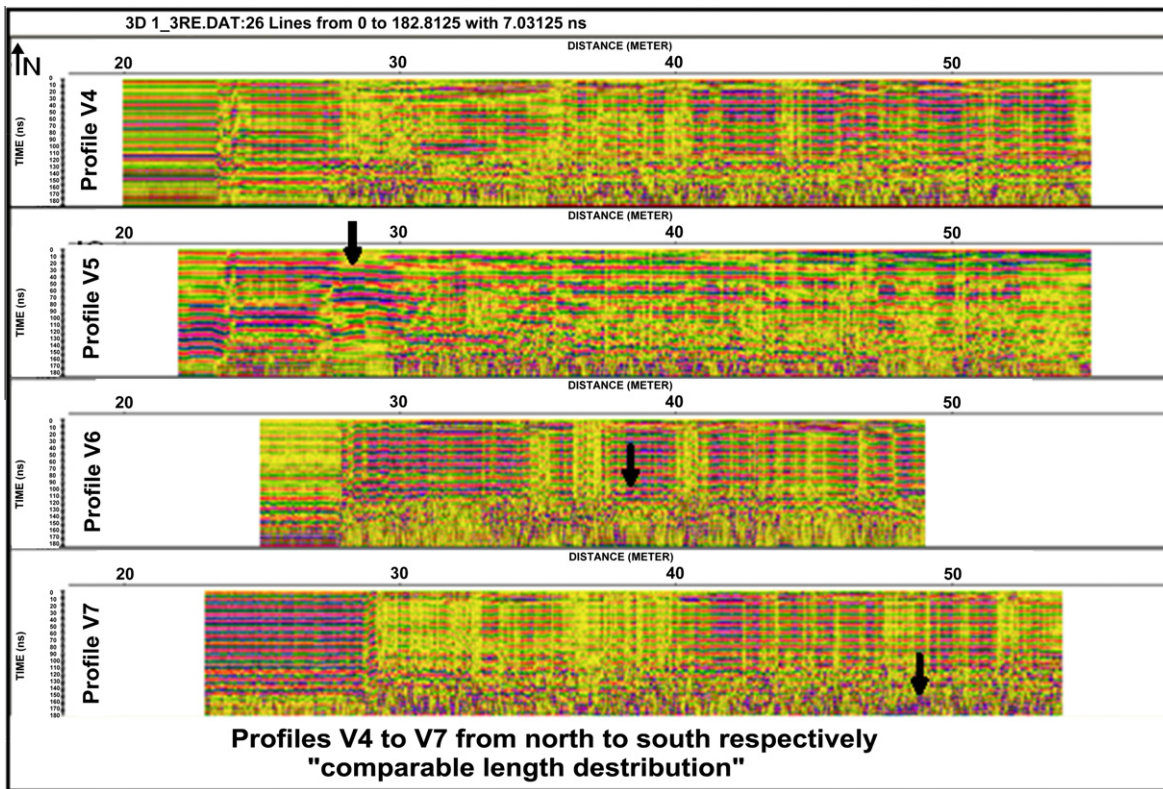


Fig. 10 The data set (B) showing profiles V4, V5, V6, and V7 from top north to down south.

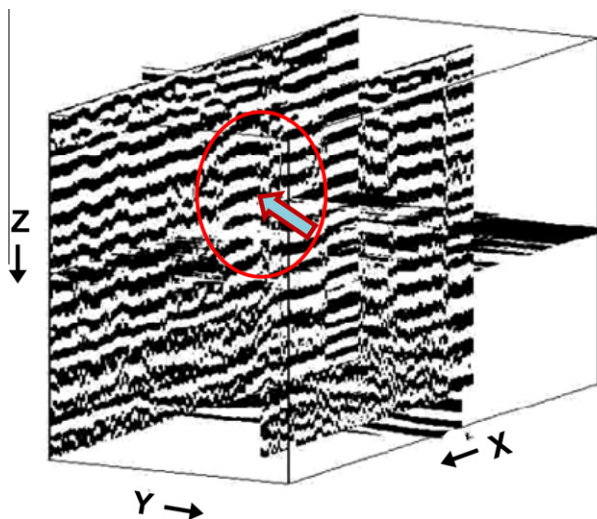


Fig. 11 3D intersection presentation of V5, a virtual section at its midpoint and a time slice at 120 ns. The arrow refers to an archaeological object.

shadow amplitudes in Fig. 13. The 3D surface and shaded presentation of the amplitudes of the same 2D time slices provided the information about the two horizontal dimensions (the in-line & cross line) and the third dimension (time increase). The arrows refer to objects could be related to the main complex; the shaded image reflects the possibility of some minor structures including small objects. The surprise is disciplined distances among them, furthermore, they form a possible

complex parallel on its longitudinal axis to the entrance corridor to the main gate.

*Interpretation of data set (C)*

The data set (C) is proposed to study the EW Sphinx Avenue; therefore, the profiles V8 and V9 have been conducted along the extension of the two sides of the corridor of the Sphinx Avenue, as the profile V10 intersected the corridor direction (Fig. 4). On profiles Mut V8 and Mut V9 (Fig. 14), it is easy to notice that the object reflections are comparable, and good for guess, to be Sphinx remains or foundations, they are marked with arrows, furthermore, a significant zonal area referred to as cultural zone on the GPR record. The reflections within this zone are located on almost equal distances and on a discipline way comparable with those objects that have been detected on the time slice representing the data set (B) on a comparable depth.

The GPR record along the profile Mut V10 (Fig. 15) is crossing Mut V8 and Mut V9 and also the corridor of Sphinx Avenue. The record reflects the finding of information about the buried materials. Analyzing such information in terms of archaeological significance requires more profiles to put it in a data set. However, the borders of the Avenue are detectable on the GPR record.

*Archaeological re-evaluation of the measuring site*

The site is quite interesting, the GPR investigation during the present reveals more than a question concerning the possible



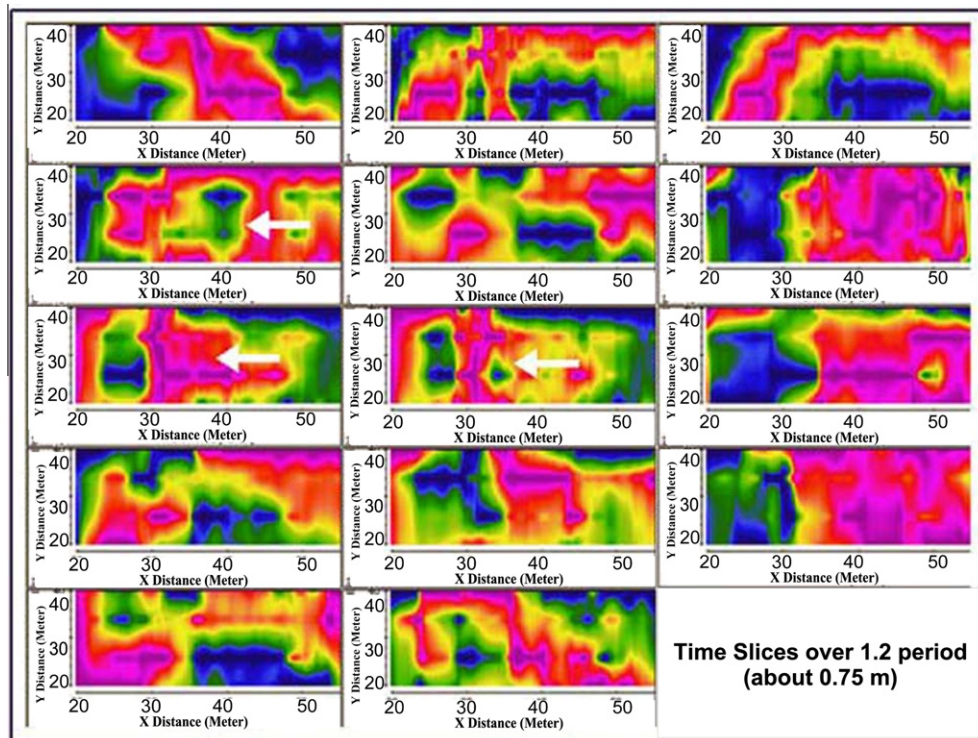


Fig. 12 2D time slices over 12 ns up to 156 ns.

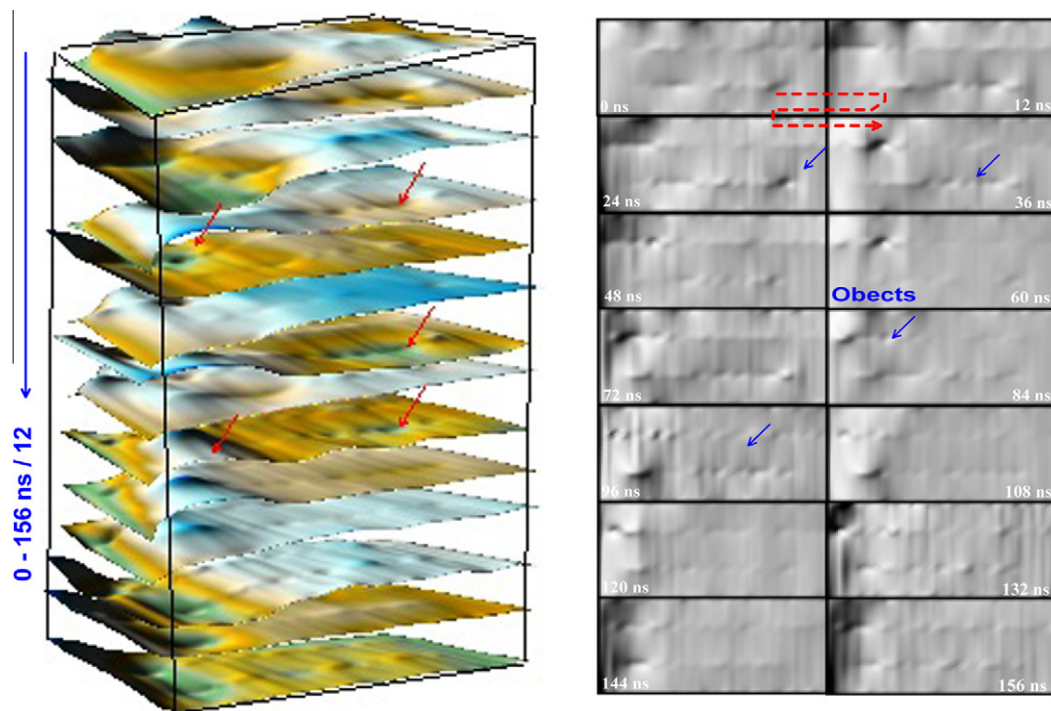


Fig. 13 3D surface and shaded presentations of 2D time slices; 12 ns interval from 0 to 156 ns.

existence of findings, the cultural layer, and the ruins of Sphinx. It looks that, the site western to the holy lake has been excavated before but not for enough depth. The GPR record shows the possibility of finding a burial at about 8.5 m depth. The data set (B) gives a high light for an object, it is slightly

inclined. In addition, the position of Mut temple between the temple of Luxor and Al Karnak temple on a line parallel to the River Nile “the life giver” spot lights on the significance of the temple towards the meaning of life in the believe of the ancient Egyptians.

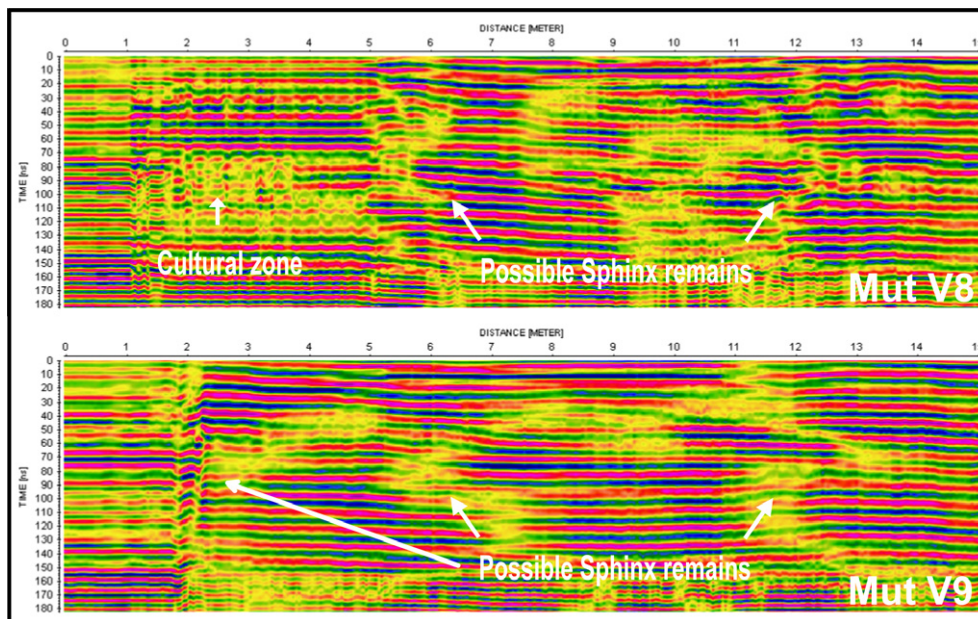


Fig. 14 The GPR profiles Mut V8 and V9.

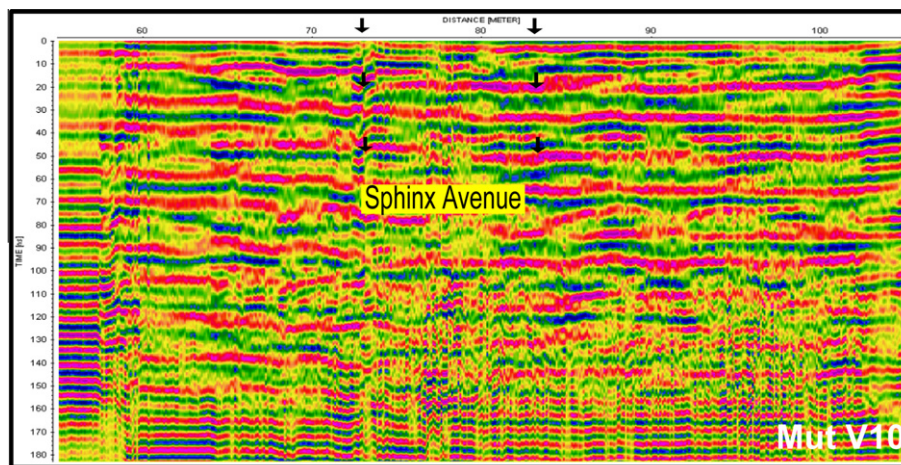


Fig. 15 The GPR profile Mut V10.

## Conclusion

The temple of the Mut is still virgin temple. The recent study together with the previous works applied to the temple is not enough to reveal the secrets of its construction. Therefore, the site is getting specific significance for archaeologists and geophysicists. Within this paper, the archaeological reports by the local inspectorate and the different missions have been evaluated and used to plan for the survey in correspondence to the surface clearance allow.

Under this scope, three GPR data sets (A, B, and C) have been acquired in/outside the temple complex; the data set (A) is oriented to study the western area of the sacred lake, it produced that some detected objects of artifacts could be related to the lake side installations. Further investigations with detailed GPR survey lines in integration with other shallow geophysical techniques are needed to reveal the entire case.

The data set (B) has been acquired outside the temple in the yard between the Mut temple and Al Karnak temple on the west of the Sphinx Avenue south to north corridor; the results of this facilitate the outline of the cultural layers and some deeper objects underneath the former excavations. The data set (C) is oriented to study the EW corridor of the Sphinx Avenue, therefore V8 and V9 have been carried out on the northern and southern sides of the corridor respectively. As V10 intersected with the corridor; this data set leads to get more information about the Avenue, as its margins and some defunct remains have been allocated.

According to the concluded results, the authors highly recommend some more profiles over closer profile intervals to clarify the in-between situation. Furthermore, it is recommended to integrate some other tools like the magnetic gradiometer FM15, resistivity scanner RM16, and/or the electromagnetic profiler GEM300.

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